Solar Thermal System Primer

City of Flagstaff – Building & Safety Program
16 December 2008

Introduction & discussion: The push towards more "green" and "sustainable" construction methods and improvement of systems that provide environmental controls has generated a flood of questions from clients wanting more than basic information. The need for a primer on the subject of thermal solar is needed so consumers can find enough information to be relatively Sauvé in discussing projects with contractors, builders and designers.

What are the savings in using Solar Thermal?; it depends upon the size of the system and the needs of your family and the way you currently heat your water. The average annual cost for water heating is usually over half the annual gas bill. UniSource indicates for Flagstaff that the number is about 40%. Typically a person uses between fifteen and twenty-five gallons of hot water a day, which can cost $5.00 to $25.00 per person every month. A family of four could be spending between $384 and $1200 a year just for heating water. A gas bill is charged at varying rates or tiers, and the most costly level or tier is levied in winter, when you are using the most gas.

[The information below was gathered from an actual residence, 2750 square feet of livable, owners use a programmable thermostat, supplement heat with a pellet stove and try to keep the house 64-66 degrees during the day and let it cold sink to 54-57 degrees overnight. The home has two gas HW heaters and a hot tub. The figures are from 2008; both natural gas and electricity. A 5.4 Kwh PV solar system was installed in June 2008]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	$235	$87	$64	$85	$71	$51	$44	$32	$34	$29	$35	$124
Gas -CCF	234	78	44	61	47	31	32	17	18	15	19	105
	$127	$436	$163	$155	$206	$147	$169	$76	$31	$29	$24	$76
Elec - Kwh	1218	4232*	1523	1439	1380	1029	1160	440	226	205	163	396

* Short circuit discovered in pond heater unit

A thermal solar water heater could potently save $370 per year off the UniSource bill (40%). Home owner is already seeing a $90/month electrical savings

Terms and definitions:

Passive solar and Active Solar: **Active solar systems** rely upon moving mechanical parts in order to transport heat, while passive units simply use the sun to accomplish this action. The bulk of systems installed in Southern California are active because they are considered to be more efficient and attractive. However, most of the systems installed worldwide are passive because they are simple and need no auxiliary power (i.e. electricity) to operate.

Active solar systems can further be divided into the following types: open loop, closed loop, drain-down, drain-back, direct or indirect, single tank or two tanks. This discussion will concentrate on open loop direct systems, since this type is the most efficient and is also the most prevalent system used in the So Cal region. The collector is usually a copper tube and fin absorber enclosed with an insulated aluminum frame or "box", covered with a low-iron tempered glass glazing. The water contained within the gas or electric water heater is circulated through the solar panels in a single tank system, or a separate tank is used to pre-heat the water before it enters the conventional water heater in a two-tank system. The two-tank system can provide as much as ninety percent of the annual hot water needs and a single tank system can be expected to contribute up to sixty percent (or more if managed). The water being circulated is gradually heated and daily temperatures as high as 160 degrees F can be expected. A reliable automatic control to operate the pump is essential. Fortunately, pumps and electronic controls have evolved and can be expected to provide over twenty years (and counting!) of service.

Passive solar systems can be divided into two types: Thermo siphon and Integral Collector Storage (ICS). Passive solar systems are popular because of their simplicity and inherent reliability. The storage tank is located on the roof and heating effect of the sun causes warm water to circulate within it. Cold water from the city flows directly to the tank on the roof, and then flows to a conventional water heater located on the ground level. It is desirable to keep the distance between the solar system and ground level water heater as short as possible in order to reduce the amount of cold water sitting in the pipe between the two units. In the case of a thermo siphon system, an insulated tank will prevent the loss of stored heat during the night. The ICS or "batch" heater is the simplest kind of solar heater, but the exposure of the storage unit to night air causes significant heat loss and precludes the use of this kind of panel in all but the mildest climates.

Drain back solar thermal: Like anti-freezing systems, drain-back solar systems are also specifically conceived for cold climates, and offer lower maintenance and longer life and reliability, but they pose high demands in terms of design.

Closed loop solar thermal (active pressurized systems):

British Thermal Unit (BTU): The amount of energy it takes to raise the temperature of water in one gallon of water, 1 degree (F). The formula is 8.33 BTU per gallon per one degree of rise.

BTUH: This is British Thermal Units per *hour.*

Calorie: The ***calorie*** is a pre-SI unit of energy equal to about 4.184 J. The calorie is specifically a measurement of heat.[1] In most fields, its use is archaic, and the SI unit of energy, the joule, has become accepted. However, it remains in common use as a unit of food energy. It was first defined by Professor Nicolas Clément in 1824 as a kilogram-calorie, and this definition entered French and English dictionaries between 1841 and 1867. Etymology: French *calorie*, from Latin *calor* (heat). The unit calorie has historically been used in two major alternate definitions that differ by a factor of 1,000:

- The **small calorie**, **gram calorie**, or **calorie** (symbol: **cal**) is the amount of heat (energy) required to raise the temperature of one gram of water by 1 °C.

Draft: Draft is an undesired local cooling of the human body caused by air movement. This is a serious problem, not only in many ventilated buildings, but also in automobiles, trains and aircraft. Draft has been identified as one of the most annoying factors in offices. When people sense draft, they often demand higher air temperatures in the room or that ventilation systems be turned off.

Heat transfer: The basic "easy" definition is that hot moves to cold. This is true for insulated spaces, liquids and various materials. For the discussion of thermal solar, the sunlight is amplified through the glazing on the collector and the cooler water in the coils is heated, thus raising the temperature of the water was it circulates through the collector. As the heated water moves to the storage tank, then the cold water is heated by the hot water. The water in the coil is cooled down and pumped back to the collector to gain more heat. The process continues as long as the pump is operating. Depending upon the size and design of the system, the collector will then transfer energy (in the form of hot water) to the storage container (tank).

Maximum temperature and pressure: Although systems can be specially designed to exceed the code requirements, the maximum water pressure for the solar thermal tank storage will be 200 psi and the maximum temperature will be 200 degrees (F) in accordance with Section 606.5.9 of the 2006 IPC. Systems beyond these pressures and temperatures must be designed by an Arizona design professional (registered Mechanical and Electrical Engineer) and will not be provided for residential use.

Solar efficiency

Evacuated tube collectors: Heat Transfer[BN] delivers nearly 40,000 BTU per panel per day. Each panel has 30 individual tubes mounted on a stainless steel rack, weighs about 210 pounds per rack and trade prices are about $2,100 per panel (1-800-323-9651 or htproducts.com)

Solar Systems: Chapter 14, pages 103-104 of the 2006 International Mechanical Code will govern the Installations, Type of Heat Transfer Fluids and General requirements for all Solar Thermal systems. Elements using PV Solar collection systems are covered in the National Electric Code, 2005 Edition, Article 690.

Solar collectors:

Solar water heating (SWH) is a technology that every homeowner can use to save on utility bills. Many Solar Domestic Hot Water (sdhw) systems were installed at the turn of the century (early 1900's) in Southern California before natural gas became predominant.

Expansion tank: As water absorbs heat (energy), the molecules of water are "excited" and expand. This expansion of the water volume increases pressure in a closed vessel (pipes, tanks, sealed containers). The use of an expansion tank (normally offset with air pressure) is to allow the heated water somewhere to move into without releasing the pressure and energized water into the atmosphere. Very similar to watching water boil in a pan on the stove. If the lid is placed over the plan, the water will rise, continue to bubble and eventually over-flow the top of the pan or "boil over". This tank allows the thermal expansion to continue, but in a controlled environment.

Standard solar holding tank(s): These hot water holding tanks are normally not active (doesn't have a gas burner between to add energy to the water). They may be equipped with an electric heating element to maintain a minimum water temperature during long periods of cloudy weather with no solar heat gain. The tanks will have coils that allow cold water to be circulated through the tank to gain heat before moving to the dispensing fixer (washing machine, shower, bathtub, sink, etc.)

Pressure relief valve (PRV): A pressure-activated valve held closed by a spring or other means and designed to relieve pressure automatically at the pressure at which such valve is set. Ref Section 202 of 2006 IPC. The pressure relief valve must be set for 210 degrees; Section 504.5, Chapter 5. (when temperatures exceed this, either a demand must be established, make up water to cool it down is injected or the relief valve is activated.)

Temperature and pressure relief (T&P) valve. A combination relief valve designed to function as both a temperature relief and a pressure relief valve. Ref. Section 202 of 2006 IPC.

Thermal expansion control: A means of controlling increased pressure caused by thermal expansion shall be provided where required in accordance with Sections 607.3.1 and 607.3.2; page 46, 2006 International Plumbing Code (IPC).

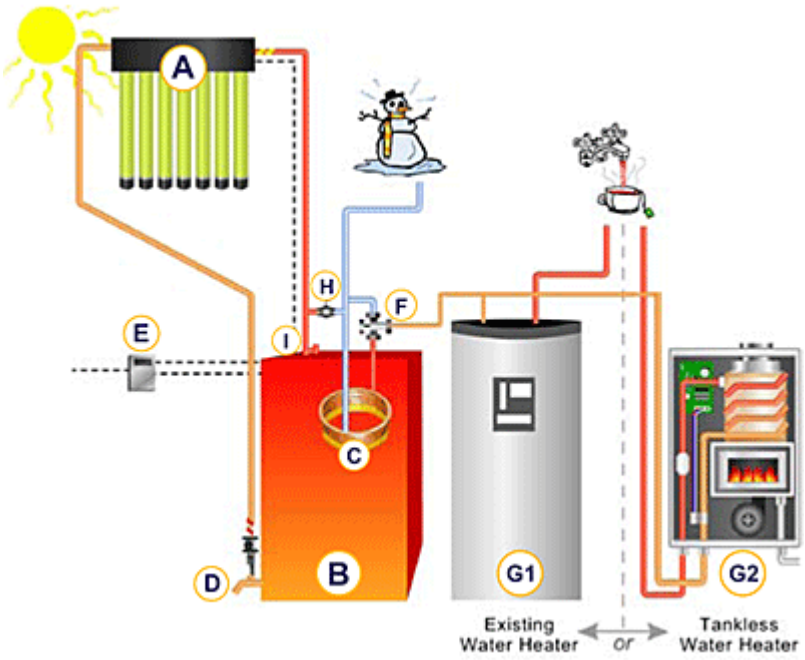
Sensors:

Basics of Design: The following is used to calculate the load requirements for either room heating or hot water generation. Certain parameters are presented for starting points and can be adjusted for the various circumstances that the designer encounters.

When determining what size collector you need, you must consider two key factors: insulation level and energy requirements. Energy requirement will usually take into consideration the volume of water and rise in temperature required. Once you know these factors you can determine the size collector you require. The bigger the collector you have, the more hot water, but you should make an economically sound decision. Generally it is wise to select a size which will provide you with 90% of your hot water needs in the summer.

Although it may seem strange to use a value of only 90% for summer solar contribution, it is for good reason. It is normal to size based on 100% of your summer hot water energy needs, with a percentage provided throughout other months, lowest obviously in winter. That is based on normal water usage, but often, and particularly in the summer, water usage patterns may not be that normal, with cooler than normal showers taken in hot weather, and greater possibility of the house being vacant for one or two days each week (weekends). As such, using a target value of 90% will probably actually result in a system that is able to supply more than 100% of your hot water needs in the summer, without excessive heat production, which can lead to water loss via pressure release and a waste of energy.

If you get an answer that is not a standard size, as a general rule, select the next size down - this will prevent having too much heat in the summer.



A. Solar collectors
Trendsetter© Evacuated Tubes

B. Solar Storage tank
Non-pressurized insulated water storage tank

C. Heat exchanger
24 sq ft of copper finned tubing ¾" inside diameter

D. Solar pump
Pumps water through solar panels

E. Solar controller
Turns solar pump on and off automatically

F. Tempering valve
A safety device to cool down the solar hot water if necessary

G1. Existing water heater
Use existing water heater or replace with tank-less water heater (G2)

H. Fill valve
Used to maintain water level in the solar tank

I. Vacuum breaker/breather
Allows for drain down of solar collector and atmospheric pressure in tank

Hot water generation:

Basic water source (assume that water is obtained from the City potable water system, temperature will vary, however for this example the designer will use water at 45 degrees – starting temperature).

Desired temperature of storage unit is 160 degrees. (Thermal solar generation is capable of very high temperatures. A system without proper controls and safety devices could easily reach 240 degrees; this is well above boiling)

NOTE: Chapter 5, International Plumbing Code, limits water heaters to 140 degrees without an ASSE 1017 master thermostatic mixing valve. For temperatures over the 140 degrees, the mixing valve limits the temperature to 140 degrees to the potable water supply. This safety features prevents scalding and discharges of the pressure/temperature relief valve when properly installed and inspected.

Temperature difference is 160 degrees – 45 degrees or 115 degrees

Tank size is 80 gallons

Amount of energy required to raise the temperature is 115 degrees x 80 gallons x 8.33 BTU/gallon. Therefore, with will take 76,636 BTUs to raise the temperature inside the storage tank to 160 degrees.

Depending upon the collector used, a typical panel (4' x 10') will generate between 30,000 and 40,000 BTU on a good sunny day and it will drop to about 10,000 BTU on a cloudy day. Using the average between the high end and the low end, one could expect 22,500 BTU from one panel. Assuming that the system had no heat loss (which of course isn't practical), it would take 3.4 days of operation for a system to reach the ideal temperature of 160 degrees in the 80 gallon tank. Most designers will want to reduce this, so they will increase the number of collectors. Using the same information, the property owner could reach the design temperature in 1.7 days with two collectors. Obviously, a good sunny Arizona day (summer or winter) could each the desired design temperature in one day.

With automatic controls that sense the temperature in the drain-back expansion tank, or in the domestic water tank, the draw down of hot water will depend upon the usage.

Usage: How is the hot water used? People wash clothes (47 gallons per load for an older washing machine to 15 gallons for the energy saving machines), take baths/shower, clean dishes, cooking, and misc. projects.

COSTS: Reference: House-energy (www.house-energy.com/Solar/Prices-Hot-Water). As a general note, prices will continue to fluctuate and this information is only for a starting point. Individuals doing the work themselves can save labor costs. The property owner needs to check the conditions and requirements for rebates, as many will require that a licensed plumbing contractor be engaged for rebate eligibility.

- ✓ In today's US market, the average price of an active solar hot water system is around $2,500 - $4,000 per home. Most of these systems have a production of about 50-100 gallons of hot water per day.

- ✓ Thermo-syhon solar hot water tank; 80-gallon is about $1,200; 40-gallon tank is about $1,000

- ✓ Drain-back retro-fit systems (80-120 gallon systems) $2,000 - $3,000

- ✓ Active systems with pumps and controls, 80 gallon systems – $3,300

These prices do not include installation or contractor/installer fees. In the City of Flagstaff, local designer/installers report that dual 80 gallon tanks, 3-4 collector systems, with pumps, controls, rack mounting systems, testing, permits and without the requirement for engineering, range from $7,500 - $ 11,500 before rebates. Both APS and UniSource will offer incentives for thermal solar installations. APS is currently more generous in offering up to 50% of the cost of installation; UniSource is more restrictive to a specific dollar amount. There are specific conditions for each, so check before you dive in.

See these web site for more information:

http://www.aps.com/main/green/choice/choice_14.html

In addition to these rebates, there is a Federal tax incentive (up to 30% of the cost of the installation that can also be claimed for qualified installations until 2016). Recommend that you carefully check with your installer, the rebate provider and your tax consultant so that you are familiar with all the requirements before investing.